CHAPTER 29

GROUNDING

29-1. General grounding systems

Reasons for grounding include electrical safety, effective lightning protection, diminishing electromagnetic coupling (EMC), and protection against electromagnetic pulses (EMP). Grounding practices and stipulations are well defined in documents published by the Institute of Electrical and Electronics Engineers, Inc. (IEEE), American National Standards Institute (ANSI), National Fire Protection Association (NFPA), and U.S. Department of Defense (DoD). Grounding is provided to limit potential (voltage) differences to values that will not cause undue hazards to personnel and equipment. A ground system that provides adequate current-carrying capacity and a low resistance path to an earthing connection will dissipate, isolate, or disconnect overpotential areas resulting from fault overcurrents or surge overvoltages. A ground path can consist of single or multiple conductors whose connection provides adequate thermal and conductance capacities. The earthing connection is generally a metallic electrode such as a rod, a water pipe, a counterpoise, or a ground grid system installed below grade.

29-2. Types of grounding

Electrical power distribution systems can be either ungrounded, solidly grounded, or resistance grounded.

a. Ungrounded system. An ungrounded system is one in which there is no intentional connection between the neutral or any phase and ground. Ungrounded system implies that the system is capacitively coupled to ground. The neutral potential of an ungrounded system under reasonably balanced load conditions will be close to ground potential because of the capacitance between each phase conductor and ground. When a line-to-ground fault occurs on an ungrounded system, the total ground fault current is relatively small, but the voltages to ground potential on the unfaulted phases will be high. If the fault is sustained, the normal line-to-neutral voltage on the unfaulted phases is increased to the system line-to-line voltage (i.e. square root of three times the normal line-to-neutral value). This, over a period of time, breaks down the line-to-neutral insulation and hence results in insulation failure. Ungrounded system operation is not recommended because of the high probability of failures due to transient overvoltages caused by restriking ground faults. The remaining various grounding methods can be applied on system grounding protection depending on technical and economic factors. The one advantage of an ungrounded system that needs to be mentioned is that it generally can continue to operate under a single line-to-ground fault without an interruption of power to the loads.

b. Solidly grounded system. A solidly grounded system is one in which the neutral (or occasionally one phase) is connected to ground without an intentional intervening impedance. On a solidly grounded system, in contrast to an ungrounded system, a ground fault on one phase will result in a large magnitude of ground current to flow, but there will be no increase in voltage on the unfaulted phase. Solid grounding is commonly used in low voltage distribution systems. Solid grounding has the lowest initial cost of all grounding methods. It is usually recommended for overhead distribution systems supplying transformers protected by primary fuses. However, it is not the preferred scheme for most industrial and commercial systems, again because of the severe damage potential of high magnitude ground fault currents.

c. Resistance grounded system. Limiting the available ground fault current by resistance grounding is an excellent way to reduce damage to equipment during ground fault conditions, and to eliminate personal hazards and electrical fire dangers. It also limits transient overvoltages during ground fault conditions. The resistor can limit the ground fault current to a desired level based on relaying needs. At the occurrence of a line-to-ground fault on a resistance grounded system, a voltage appears across the resistor that nearly equals the normal line-to-neutral voltage of the system. The resistor current is essentially equal to the current in the fault. Therefore, the current is practically equal to the line-to-neutral voltage divided by the number of ohms of resistance used. The grounding resistances are rated in terms of current and its duration for different voltage classes.

(1) Low resistance grounding refers to a system in which the neutral is grounded through a small resistance that limits ground fault current magnitudes. The size of the grounding resistor is selected to detect and clear the faulted circuit. Low resistance grounding is not recommended on low voltage systems. This is primarily because the limited available ground fault current is insufficient to positively operate series trip units and fuses. These trip units and fuses would be dependent upon both phase-to-phase and phase-to-ground fault protection on some or all of the distribution circuits. Low resistance grounding normally limits the ground fault currents to approximately 100-600A. The amount of current necessary for selective relaying determines the value of resistance to be used.

(2) High resistance grounding refers to a system in which the neutral is grounded through a predominantly resistive impedance whose resistance is selected to allow a ground fault current through the resistor equal to or slightly more than the capacitive charging current of the system. Because grounding through a high resistance entails having a physically large resistance that is both bulky and costly, high resistance grounding is not practical and is not recommended. However, high resistance grounding through a grounding transformer is cost effective and accomplishes the same objective. High resistance grounding accomplishes the advantage of ungrounded and solidly grounded systems and eliminates the disadvantages. It limits transient overvoltages resulting from a single phase-to-ground fault by limiting ground fault current to approximately 8A. This amount of ground fault current is not enough to activate series overcurrent protective devices, hence no loss of power to downstream loads will occur during ground fault conditions. Special relaying must be used on high resistance grounded systems in order to sense that a ground fault has occurred. The fault should then be located and removed as soon as possible so that if another ground fault occurs on either of the two unfaulted phases, high magnitude ground fault currents and resulting equipment damage will not occur. High resistance grounding is normally applied in situations where it is essential to prevent unplanned system power outages, or previously the system has been operated ungrounded and no ground relaying has been installed. Once the ground point has been established through the resistor, it is easier to apply protective relays. The user may decide to add a ground overcurrent relay. The relay may be either current actuated using a current transformer or voltage actuated using a potential transformer. Depending on the priority of need, high resistance grounding can be designed to alarm only or provide direct tripping of generators off line in order to prevent fault escalation prior to fault locating and removal. High resistance grounding (arranged to alarm only) has proven to be a viable grounding mode for 600V systems with an inherent total system charging current to ground of about 5.5A or less, resulting in a ground fault current of about 8A or less. This, however, should not be construed to mean that ground faults of a magnitude below this level will always allow the successful location and isolation before escalation occurs. Here, the quality and the responsiveness of the plant operators to locate and isolate a ground fault is of vital importance. To avoid high transient overvoltages, suppress harmonics and allow adequate relaying, the grounding transformer and resistor combination is selected to allow current to flow that equals or is greater than the capacitive changing current.

29-3. Grounding systems

Basically six types of grounding systems are used. They are static grounds, equipment grounds, system grounds, lightning grounds, electronic (including computer) grounds, and maintenance safety grounds. All of these systems are installed similarly. However, their purposes are quite different. Some of the systems carry little or no current. Others carry small to moderate currents at 50 or 60 Hz. Still others must be able to carry currents over a very broad range of frequencies in order to be considered effective.

a. Static grounds. A static ground is a connection made between a piece of equipment and the earth for the purpose of draining off static electricity charges before a spark-over potential is reached. The ground is applied for more than just the comfort of the equipment operator. The possibility of an explosion ignited by an electrical spark must be considered. Dry materials handling equipment, flammable liquids pumps and delivery equipment, plastic piping systems, and explosive storage areas all need static ground protection systems installed and functioning properly. Static ground systems are generally not called upon to conduct much current at any given frequency. Smaller gauge, bare conductors, or brushes with metallic or conductive bristles make up most parts of the static ground system.

b. Equipment grounds. An equipment ground pertains to the interconnection and connection to earth of all normally non-current carrying metal parts. This is done so the metal parts with which a person might come into contact are always at or near zero volts with respect to ground thereby protecting personnel from electric shock hazards. Equipment grounding consists of grounding all non-current carrying metal frames, supports, and enclosures of equipment. All these metallic parts must be interconnected and grounded by a conductor in such a way as to ensure a path of lowest impedance for the flow of ground fault current from any line to ground fault point to the terminal at the system's source. An equipment grounding conductor normally carries no current unless there is an insulation failure. In this case the fault current will flow back to the system source through the equipment grounding conductors to protect personnel from electrical shock. The equipment grounding conductor must never be connected to any other hot lines. Equipment grounding systems must be capable of carrying the maximum ground fault current expected without overheating or posing an explosion hazard. Equipment grounds may be called upon to conduct hundreds to thousands of amperes at the line frequency during abnormal conditions. The system must be sized and designed to keep the equipment surface voltages, developed during such abnormal conditions, very low. An example of this system is the bare copper wire (green conductor) connected to the frames of electric motors, breaker panels, outlet boxes, etc. Electrical supporting structures such as metal conduit, metal cable trays, or metal enclosures should be electrically continuous and bonded to the protective grounding scheme. Continuous grounding conductors such as a metallic raceway or conduit or designated ground wires should always be installed from the ground grid system to downstream distribution switchboards to ensure adequate grounding throughout the electrical distribution system. Part of the equipment ground is also formed by the switchgear ground bus.

c. System grounds. A system ground refers to the condition of having one wire or point of an electrical circuit connected to earth. This connection point is usually made at the electrical neutral although not always. The purpose of a system ground is to protect the equipment. This ensures longer insulation life of motors, transformers, and other system components. A system ground also provides a low impedance path for fault currents improving ground fault relaying selectivity. In a properly grounded system the secondary neutral of a power transformer supplying a building or facility is connected to a transformer grounding electrode. The transformer neutral is a part of the service entrance point that bonds to the grounding electrode system of the building. According to the National Electrical Code (NEC), NFPA 70, articles 250-81 and 250-83, metal underground water pipes, metal building frames, encased electrodes, rods, and plates are among the items that can make up the grounding electrode system of a building. The NEC article 250-83 requires that the size of the grounding electrode iron or steel rod must be at least 5/8 inches in diameter and driven eight feet deep. The resistance of the electrode to ground cannot exceed 25 ohms (NEC 250-84). Otherwise a second electrode should be added, and the distance between the two electrodes must be at least six feet. However, in some systems the 25 ohms resistance value cannot achieve the goals of grounding. They require ground resistance values below ten ohms. If the main building load is composed of computers or sensitive electronic equipment, the earth ground resistance should not exceed five ohms. There are many methods of system grounding used in industrial and commercial power systems, the major ones being ungrounded, solid grounding, and low and high resistance grounding. Factors which influence the choice of selection include voltage level of the power system, transient overvoltage possibilities, types of equipment on the system, cost of equipment, required continuity of service, quality of system operating personnel, and safety consideration including fire hazards.

d. Lightning protection. Main lightning protection grounding requirements are dependent upon the structure, component, or system to be protected. See chapter 30 for detailed discussion of lightning protection systems.

e. Electronic and computer grounds. Grounding for all electronic systems, including computers and computer networks, is a special case of the equipment ground and the system ground carefully applied. In fact, grounding systems for electronic equipment are generally the same as for system ground with an additional requirement: the degree of performance required. Electronic equipment grounding systems must not only provide a means of stabilizing input power system voltage levels, but also act as the zero voltage reference point. However, the need to do so is not restricted to a low frequency of a few hundred hertz. Grounding systems for modern electronic installations must be able to provide effective grounding and bonding functions well into the high frequency megahertz range. Effective grounding at 50-60 Hz may not be effective at all for frequencies above 100 kilohertz. There are several aspects to the requirement for good grounding performance for electronic equipment, all of which are due to electrical circuit behavior. Good electronic system grounding performance is achieved with a properly laid out distribution of multipoint, well bonded grounding connections. This system can use bare, braided, sheet, or stranded copper conductors for grounding or bonding functions. This system requires conduit and equipment enclosure bonding at all junction points. In other words, simple metallic contact between the enclosures, wiring conduits, and power panels is not enough. The multipoint bonding provides low impedance grounding for the electronic equipment. The low impedance between the separate items of electronic equipment keeps the noise voltages at or near zero between them and, therefore, provides an "equipotential plane." This system is much easier to inspect and test. No special requirements must be met during modifications or expansion of the electrical system. All power panels and all supply transformers feeding an installation with this type of grounding system must be grouped and bonded together using short lengths of bare, braided, sheet, or stranded copper conductors in order to achieve the effective high frequency grounding performance described above. A single area of power entry with a large equipotential ground plane and short equipment grounding conductors forms the preferred grounding system for large automated data processing (ADP) and computer applications.

f. Maintenance safety grounds. Grounds used for maintenance work are usually intentional, but temporary, connections between equipment power conductors and ground. These connections are always applied after the power source has been turned off and the circuit(s) have been tested and are known to be de-energized. The ground is intended to protect maintenance personnel from an inadvertent re-energization of the circuit. The ground is removed after maintenance operations have been completed.

29-4. Ground system materials and testing requirements

Several factors can degrade initial good grounds. These factors indicate the importance of continuous periodic testing of grounding systems. For example, water tab1es are gradually falling in many areas. Also, there are more underground installations of non-metallic pipes and conduits which do not provide low resistance ground connections. There are electric systems that are continually expanding with an associated fault current increase which may require a decrease in grounding resistance. And there are corroded connections that may increase the resistance of the ground system.

a. Testing. Periodic testing should be done to assure grounding system effectiveness. The following are points that should be addressed during inspection and maintenance:

(1) Inspect and test single point, isolated ground systems after every electrical system modification. Visually inspect outlets and panels for conductors forming loops between the equipment ground and the isolated ground.

(2) Test the ground to neutral voltage at each power distribution panel included in the particular system. The voltage should be taken using a high impedance AC voltmeter and an accurate record should be kept. The voltage should be very low; on the order of 10-150 millivolts (0.01-0.150V). Any sudden changes or increasing trends should be investigated and the cause corrected.

(3) The made electrode, rod, plate, or selected ground body contact point should be tested every 12-24 months. A record should be kept. Any increasing impedance indicates a need for remedial action.

b. Piping systems. The ground grid of the plant should be the primary system. In some cases a metallic underground water piping system may be used in lieu of a plant ground grid, provided adequate galvanic and stray current corrosion protection for the piping is installed, used, and tested periodically. This practice is not acceptable in hazardous areas and is not recommended if the piping system becomes sacrificial.

c. Resistance goals. The plant ground grid should have a system resistance of 10 ohms or less. Ground grid system resistance may be decreased by driving multiple ground electrode rods. A few rods, deeply driven and widely spaced, are more effective than a large number of short, closely spaced rods. Solid hard copper rods should be used, not copper plated steel. When low resistance soils are deep, the surface extension rods may be used to reach the low resistance stratum. Bonding of ground conductors to rods should be by permanent exothermic weld (preferred) or compression sleeve, and not by bolted clamp (corrosion results in high resistance connection). Resistance at each rod in a multiple system should not exceed 15 ohms.

d. Ground rods. Grounding electrodes (driven into the earth) maintain ground potential on all connected conductors. This is used to dissipate (into the earth) currents conducted to the electrodes. The resistance of a ground electrode is primarily determined by the earth surrounding the electrode. Test data given in IEEE 142, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (1991), indicate that about 90 percent of the total resistance of a ground lies within 6 to 10 feet (1.8 to 3 meters) from the electrode. The diameter of the rod has only a negligible effect on the resistance of a ground. The resistance of the soil is dependent upon the type of soil and its moisture content. Electrodes should be long enough to penetrate a relatively permanent moisture level and should extend well below the frost line.